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Title: Beyond viral dependence: the pathological consequences of HCV-induced EGF signaling

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Authors contributions: All authors conceived, wrote and reviewed the manuscript.

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4 Comment on: “HCV modifies EGF signaling and upregulates production of CXCR2 ligands: role
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6 in inflammation and antiviral immune response” by Christina Groepper, Kerstin Rufinatscha,
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8 Nadja Schröder, Sabine Stindt, Christian Ehling, Ute Albrecht, Hans H. Bock, Ralf
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10 Bartenschlager, Dieter Häussinger and Johannes G. Bode, published in *Journal of Hepatology*
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14 2018.
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19 Chronic hepatitis C virus infection (HCV) affects approximately 71 million individuals
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21 worldwide [1], being a major etiological factor for the development of liver cirrhosis and
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23 hepatocellular carcinoma (HCC). Acute HCV infection often progresses to chronicity and is
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25 characterized by a non-resolving liver inflammation leading to a broad range of alterations in the
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27 tissue microenvironment. About ninety percent of HCC cases arise in the context of chronic liver
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29 inflammation, highlighting the central role of this persistent immune response in disease
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31 pathogenesis [2]. Despite efficient antiviral therapy by direct acting antivirals (DAA), the risk of
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33 HCC development cannot be fully eliminated in patients with advanced liver disease [3]. In this
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35 regard, accumulating evidence suggests a potentially persisting proto-oncogenic environment
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37 created by virus-induced changes in the cell signaling [4-7]. Therefore, even in the DAA era, the
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39 understanding of virus-host interactions during chronic HCV-associated inflammation is key to
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41 identify and treat patients at high risk to develop HCC.
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48 In this context, a recent article in *Journal of Hepatology* by Johannes G. Bode’s
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50 laboratory at the Heinrich-Heine University in Germany provides a novel mechanism by which
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52 HCV infection contributes to this pathologic inflammatory response [8]. Aiming to identify
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54 chemokines regulated by HCV, the authors performed a functional screen using an HCV
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56 subgenomic replicon system and identified an HCV-induced upregulation of C-X-C motif
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4 chemokine receptor 2 (CXCR2) ligands (CXCLs) 1, 2, 3 and 8. Consistently, similar results were
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6 obtained upon HCV infection using the cell culture-derived strain JC1. Having previously shown
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8 that HCV infection enhances epidermal growth factor (EGF) signaling, the authors next explored
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10 the possible involvement of this pathway on CXCR2 ligand expression. EGFR perturbation
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12 studies combining RNAi knockdown of EGF and the use of MAPK inhibitors, confirmed an
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14 HCV-induced upregulation of *CXCL8* via EGFR and the MAP kinase kinase MEK1.
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16 Additionally, knockdown of the p65 subunit of the NF- κ B complex was sufficient to abrogate
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18 basal and EGF-induced *CXCL8* expression in replicon-expressing cells, while in HCV-infected
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20 cells this mainly affected basal *CXCL8* levels. This suggests that the observed enhancement of
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22 chemokine expression during HCV infection not only depends on the EGFR pathway but also on
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24 the activation of additional transcription factors such as NF- κ B. The *in vivo* relevance of the data
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26 is emphasized by an association of HCV viral load with *CXCL8* serum levels in chronically
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28 infected patients. Similarly, serum levels of EGF and *CXCL8* tend to positively correlate
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30 although this did not reach statistical significance in their study cohort.

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32 In a previous study, the authors demonstrated that HCV enhances EGFR signaling via NS3/4A-
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34 mediated proteolytic cleavage of T-cell protein tyrosine phosphatase (TC-PTP), one of the major
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36 negative regulators of EGFR tyrosine-kinase activity [9]. Indeed, here they demonstrate that
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38 NS3/4A expression alone enhances EGF-inducible *CXCL8* expression, an effect that can be
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40 mimicked by knocking down TC-PTP. As the major role of chemokines is the recruitment of
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42 immune cells to the site of inflammation, the authors next evaluated if in the context of HCV
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44 replication EGF-induced release of chemokines influences leukocyte migration. Remarkably, the
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46 authors demonstrate that media from EGF-treated cell lines expressing the HCV subgenomic
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48 replicon enhances the migration of neutrophils, an effect that was not observed with EGF-
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4 conditioned media alone. This suggests that HCV infection modulates chemoattraction of
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6 immune cells to the liver via EGF-regulated chemokine secretion.
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9 The findings of Christina Groepper and co-workers are not just relevant for our
10 understanding of HCV-EGFR interaction but most importantly provide insight into the
11 pathologic consequences of derailed EGF signaling for liver inflammation and HCC
12 development (Fig. 1). EGFR is a host factor for HCV by facilitating the assembly of the host
13 entry complex, viral glycoprotein-dependent membrane fusion and cell-to-cell transmission of
14 the virus [7]. HCV requires EGFR signaling to maintain its life cycle but also induces these
15 signals itself during binding to the receptor complex [6, 10]. Moreover, during HCV infection
16 the non-structural protein NS5A prolongs EGFR signaling by perturbing its internalization and
17 subsequent degradation [11, 12]. This leads to a persistent EGFR activation during chronic HCV
18 infection that potentially contributes to an impaired antiviral response by modulating interferon
19 alpha signaling via STAT3 [13].
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35 Their finding that HCV replication promotes EGF expression is highly relevant in the study of
36 HCV-induced chronic liver disease, as the EGF pathway is a key driver associated with
37 progression towards cirrhosis [14] and HCC development [15]. Equally interesting is the
38 observation that HCV-induced EGF expression is a regulator of CXCR2 ligands. For example,
39 HCV infection has been previously described to promote CXCL8 expression, which inhibits
40 interferon antiviral activity and facilitates viral infection [16]. Hepatic CXCL8 is detected at low
41 maintenance levels during acute HCV infection, although marked increases in serum and hepatic
42 levels have been observed in HCV-infected patients with progressive inflammation and cirrhosis
43 [17]. Indeed, CXCL8, which is associated with poor outcome in HCC patients, has been
44 suggested as HCC biomarker [18]. Here, Groepper and co-workers validated a mechanistic
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4 concept between EGFR signaling and CXCL8 during HCV infection, that has been previously
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6 proposed for hepatomas [19]. Moreover, they provide a previously undescribed mechanism
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8 linking EGFR signaling to chemoattraction of immune cells. In macrophages EGFR knockout
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10 attenuates HCC development in mice [20]. EGF-mediated recruitment of neutrophils during
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12 HCV infection is potentially relevant for liver pathobiology, since it has detrimental effects on
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14 the host by contributing to the necro-inflammatory process [21].
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19 Although further studies in larger patient cohorts are needed to consolidate the model
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21 proposed by Groepper and co-workers, the impact of their findings for liver disease and its
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23 association to EGF signaling is evident [22]. In future studies, it would be very interesting and
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25 potentially relevant to follow up HCV-induced EGF expression pattern in liver tissue and blood
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27 samples before and after sustained viral response and to compare them to liver fibrosis scores.
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29 Furthermore, does HCV genotype influences EGF and chemokine expression profiles since
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31 genotype 3 is associated with more severe liver disease manifestations? Taken together, this
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33 paper represents a further corroboration for the clinical potential of HCC chemo-preventive
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35 strategies based on regulators of signal transduction. Indeed, EGFR which is phosphorylated in
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37 hepatic stellate cells (HSCs) has been successfully targeted by the clinical EGFR inhibitor
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39 erlotinib in animal models, demonstrating proof of concept that EGF-based therapies attenuates
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41 chemically induced liver fibrosis and HCC nodules [14]. Therefore, EGFR or MAPK modulators
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43 could be part of a personalized immuno-therapeutic strategy modulating chemokine profiles and
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45 inflammatory responses associated with liver disease progression.
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Figure 1: Refined model of HCV-EGFR modulation and its impact on liver disease development. HCV binding to the HCV entry receptor complex (i.e. CD81, CLDN1) at the cell surface induces EGFR phosphorylation and downstream signaling. EGFR activity is prolonged by the NS5A-mediated perturbation of EGFR internalization and degradation. As a consequence, prolonged EGFR activity is associated with an increased hepatocyte proliferation, HSCs activation, fibrogenesis and a dampened antiviral response via modulation of STAT3. Groepper *et al.*, (colored pathway) demonstrated that HCV replication enhances the expression of CXCR2 ligands (e.g. *CXCL8*) by intermediary of an EGF-dependent mechanism and activation of the NF- κ B signaling pathway. This is further favored via the proteolytic cleavage of TC-PTP by NS3/4A, resulting in increased EGFR activation. Upon EGF stimulation, the production of CXCL8 during HCV replication promotes the recruitment of neutrophils.

Figure 1: Refined model of HCV-EGFR modulation
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